Development of an Electronically Controlled Self-Teaching Lift Valve Family

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Abstract

Other than mobile hydraulics and high voltage switchgears, Bucher Hydraulics is also involved in the less-known area of hydraulic lifts. In fact, Bucher Hydraulics did invent the electronically controlled lift valve in the 1970s. Since then, Bucher Hydraulics developed a wide line of products for hydraulic elevators, such as valves and power units. In 2012, this valve family included various sizes, pressure ranges, systems with constant motor speeds, inverter-driven motors, energy-efficient solutions with hydraulic counterweight, as well as customized solutions. As the common principle, all these solutions apply an electronic closed-loop control that uses a volumetric flow sensor and a proportional actuator. Since 2012, Bucher Hydraulics is substituting this valve family with a new generation, the iValve. Every iValve uses several self-teaching algorithms to adapt to its environment. Their on-board and cabinet electronics control solenoid currents and measure flow, pressure, and temperature. These features enable the iValve to self-monitor, to adapt to operating parameters, and to analyze and log information about itself and the attached system. This report on a highly specialized product is meant to provide inspiring insights.

KEYWORDS: iValve, lift control valve, closed-loop control, electronic control, self-teaching, remote analysis

1. Function of a Hydraulic Lift

The hydraulic system of a lift is simple. The hydraulic solution is mostly chosen due to its

- Robustness, long life respectively low cost of ownership
- High power density regarding the whole building

In 95% of the cases, an oil-immersed asynchronous machine drives a screw pump with constant frequency. The lift control valve connects tank, pump, and cylinder. The cylinder pushes the load upwards either directly or indirectly via a pack of ropes. For the downwards drive, the weight of the load drives the system. In few cases, a counterweight might be present but it will never fully compensate the weight of the empty cabin. The valve block realizes most functions and features of the power unit, such as the control of all upwards and downwards speeds, manual and electric emergency lowering, a hand pump, ball valve, pressure gauge, pressure switches, a redundant emergency brake, and others.

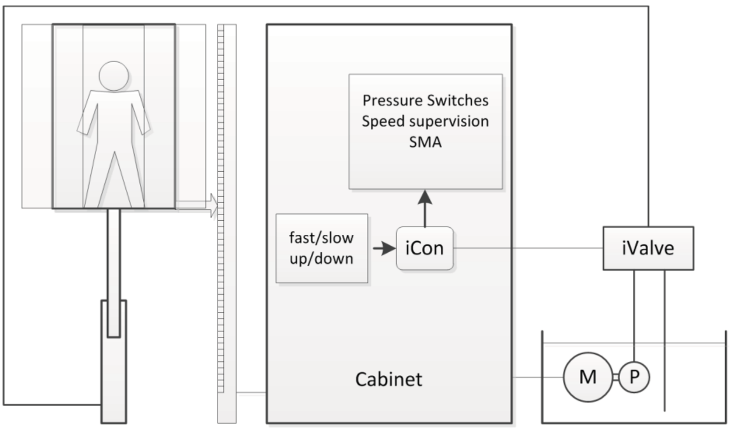

Figure 1: Hydraulic Lift Control

The master of the lift system is the cabinet, not the valve (see Figure 1). The valve in fact has no information concerning any redundant breaks, the position of the cabin or the doors, or the status of the motor. The valve receives four principal signals from the cabinet: slow up, fast up, slow down and fast down. From these signals, it calculates all transitions and dependencies. To travel upwards, the cabinet starts the motor and then signals “fast up” to the valve. Therefore, the valve’s bypass from pump to tank is normally open (see Figure 2). Receiving “fast up”, the valve will quickly close the bypass up to the point that the circulating pressure reaches the load pressure of the cylinder. After that, it will continue to slowly close the bypass carefully controlling the acceleration curve for the cabin until it reaches final travel speed. When the cabin reaches a certain position in the shaft the cabinet will switch from "fast up" to "slow up", causing the valve to decelerate to slow speed, which is approximately 10% of travel speed. The lift then travels slow speed until the cabin reaches the stop position. During the slow speed phase, the power unit bypasses approx. 90% of the volumetric flow at full load pressure. Hence, energy efficiency and oil temperature require keeping the slow speed travel short. At the stop position, the cabinet signals "stop" by taking away the signal "slow up" and the valve does an open-loop controlled soft-stop, as parameterized (3-20 mm).

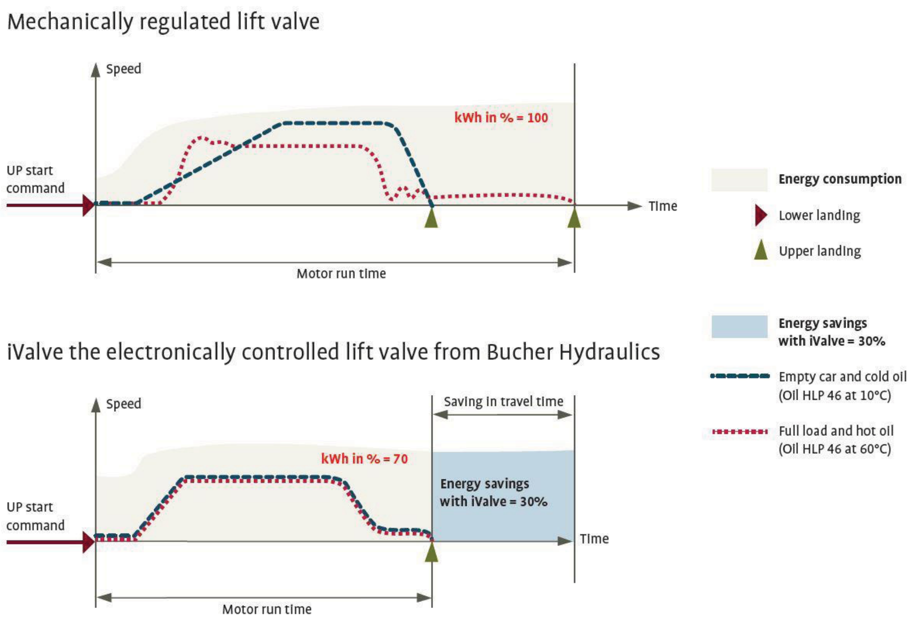

Figure 2: The Upwards Driving Curve

Travelling downwards works similar, except, the load pressure is the driving force. The oil is throttled directly from the cylinder to the tank.

2. The Environment of a Hydraulic Lift Valve

The population of lift installations is very heterogeneous. There are plunger, tele and pulling cylinders, single or tandem, direct or indirect, loads from a few hundred kilos up to several tons, travel speeds from 0.15 m/s up to 1 m/s. Units that run all day at up to 60°C and those standing in a shaft at about 0°C. Most installations run on HLP, some use biodegradable oil instead. The smallest installations use pumps with 20 l/min. The upper end is open. The pressure range is limited to 67 bar dynamic due to the cylinders and hoses you can afford including the demanded safety margins.

Also, customers are heterogeneous. While one prefers perfect ride comfort, the other prefers a significant jerk at the start and the end of the ride to signalize motion. A well designed and carefully built lift has a dynamic pressure rise of about 3 bar driving upwards. Nevertheless, more than 20 bar may occasionally occur. The worst enemy of driving comfort is the stick-slip of the cylinder and the mechanic structure. The pressure loss due to stick-slip should be less than 2 bar and can be more than 8 bar in a typical installation with 18-28 bar static load of the empty cabin.

The industrial challenge is to fulfill all (sometimes opposing) demands with the least quantity of variances and different parts. The iValve i250 (Figure 3) ranges from 20 l/min to 250 l/min - the i500 from 150 l/min to 500 l/min. Power units up to 4000 l/min can be equipped with the MultiValveSystem (MVS), an electronic option that parallelizes up to eight i500 valves in a master/slave system.

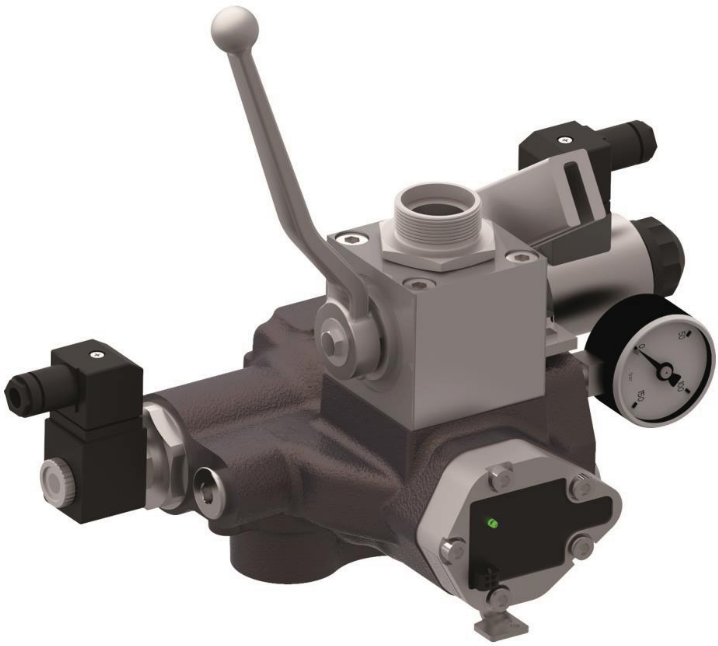

Figure 3: iValve i250

Lift companies try to safe money by reducing the installation time and, at the same time, the expertise necessary to set up the system. The above-named demands thus ought to be fulfilled without further adjustments.

A wide range of working parameters should be covered by one design and no physical adjustments, meaning that the control elements will be oversized for each single working point. This means in turn that the amplification of the elements of the control loop in the single working point will be extraordinarily high.

The ratio between the proportional signal at the pilot solenoid and the control result of the valve for example may reach 1:1.7 million. This defines the demands on design and manufacturing.

Nevertheless, craftsmen not hydraulic experts install hydraulic lifts, mostly during the construction of a building. Therefore the hydraulic power units of hydraulic lifts face an unmatched level of contamination with e.g. builder's dust. These contaminations have to be taken into account during the design phase of these piloted proportional valves.

3. Hydraulic Lift Control Valve Solutions

The demands named above often require custom-made solutions in the design phase of the lift control valve family, of which I would like to name a few below.

3.1. Pilot

A single piloted slide controls the main up- and downward-flow. Upwards, the orifice of the bypass controls the speed. The piloting pressure is taken from the pump pressure. Downwards, the speed is throttled and piloted directly from the load pressure. The dynamic pressures of the system behave inversely in up or down direction. For stability reasons and driving comfort, the pilots must follow precise rules. Therefore, the pilot of the iValve, which is situated on top of the proportional solenoid, in facts consists of two separated pilots with distinct ways of working. The up- or down pilot is chosen by a specialized start sequence.

In order to cope with the extraordinary contamination level in lift hydraulics, the valve was tested and optimized in contamination tests (see Figure 4). Today, the valve withstands a direct contamination induced through the screw pump of 2 ml test dust (KSL14027<500 µm + 20 % Fe<100 µm) in up and down travel suffering only small control errors. This test dose is limited by the capacity of the pump to withstand the contamination.

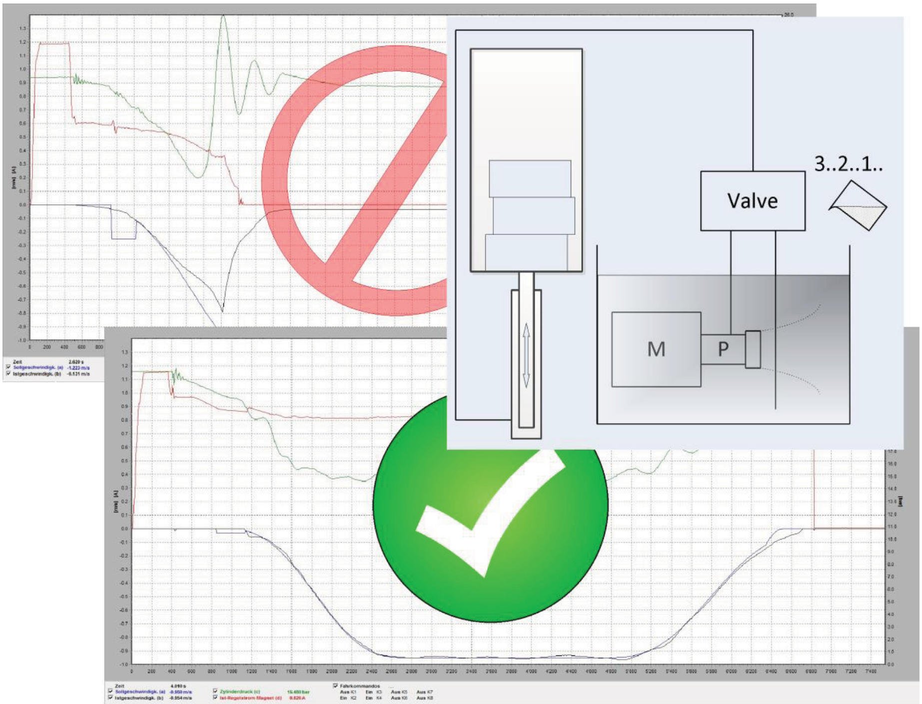

Figure 4: Contamination Test

3.2. Flow Sensing Check Valve

The proven pressure plate principle for the volumetric flow sensor is now integrated into the necessary check valve. The leakage-free check valve, on which the lift rests in standstill, not only unlocks to go downward but is poled inversely by its pilot for the up or downwards ride. So it measures the volumetric flow in both directions.

The sensor of the i250 measures (1.3 times 250 l/min =) 325 l/min during the test of the pipe rupture valve. The same sensor installed in a 20 l/min installation must control a leveling speed of 2 l/min. The viscosity ranges from 12 cSt to 500 cSt and the pressure loss – the biggest allies in favor of turbulence and viscosity independence – directly costs energy and limits possible lift designs. It must stay beyond 2 bar at 250 l/min.

Please find a detailed description of the sensor in patent /1/.

3.3. Electronics

The volumetric flow sensor joins a cluster of sensors and feedbacks, which are available to augment the perspective of the software domain. The volumetric flow goes hand in hand with the pressure, temperature and currents to the solenoids. In addition, the valve registers the command signals that it receives from the cabinet and the driving curve that it generates from the command history.

The main board situated in the cabinet called iCon (see Figure 5) and the embedded valve electronic situated in the iBox both communicate via serial interface. Combining all information, the valve can achieve knowledge on its own condition as well as the condition of the connected system.

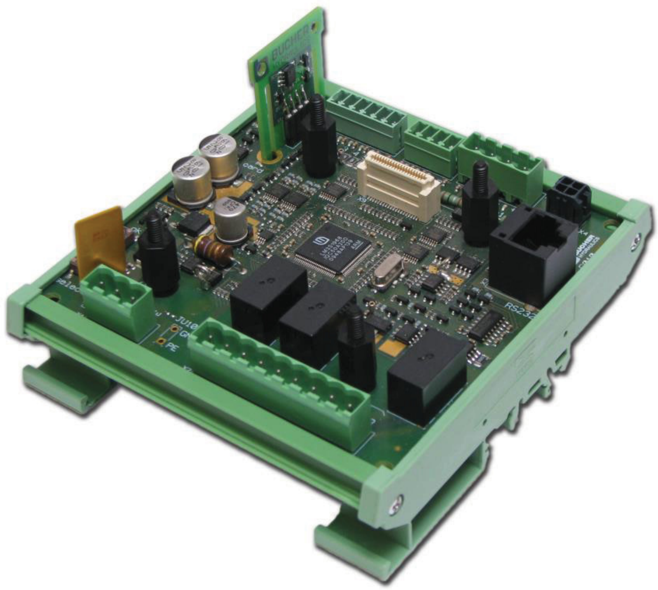

Figure 5: iCon

3.3.1. Self-Teaching Algorithms

In the first place, the sensor array is used to realize self-teaching algorithms, which aim at the main target of this development: Reducing the need to adjust the valve during installation. Today, several self-teaching algorithms optimize different aspects of the riding curve. There is for example T1, which optimizes the starting time by learning the optimal current to energize when the valve gets the first command to ride upwards or downwards after standstill. Another self-teaching algorithm - T3 - optimizes the deceleration curve of the ride in order to achieve 0.3 sec of slow speed travel time at the end of a ride at any load and any temperature upwards or downwards.

3.3.2. Self-Monitoring

Secondly, the wide range of information is used to realize features of self-diagnosis. One self-monitoring domain is the detection of safety relevant errors in the valve. During every ride the valve monitors the compliance with several requirements and sends a fail-safe signal to the cabinet – the Self Monitoring Acknowledge (SMA) – Signal. This monitoring function and signal is part of the requirements defined by the appropriate Norm DIN EN81-2 /2/.

Another self-monitoring domain is widely known as condition monitoring. The feature registers changes in the behavior of the valve and traces them back to the aging of the oil, clogging of a filter, or others. The aim is to foresee these effects before they become fatal to make service visits more projectable. In order to realize the advantages of condition monitoring by warning the service technician in advance and while still in his office, a connection must be integrated into the cabinet, because the cabinet connects to the outside. Bucher Hydraulics offers an optional electronic card - the iAccess card - for the connection via DCP0 bus protocol.

3.3.3. Diagnosis and Analysis

Thirdly, the gathered information can be used to realize a lot of character traits or errors in the connected system.

The ride quality, energy efficiency and many characteristics of a hydraulic lift not only depend on the possibilities of the lift control valve but also are often limited by properties of the system. This is obvious in a system with extraordinary friction or stick slip. Nevertheless, a scratching counterweight or irregular rails can also lead to persistent problems. A chattering relay, poor timing between commands and a motor contactor, bad wiring – countless possible electronic and software errors can lead to time-consuming issues difficult to solve. In those cases, the technician can count on an informative array of LEDs or a hand terminal, or he can directly watch the driving curves on a laptop using the software iWin. In cases when the effect occurs only once every one hundred rides, the technician can leave behind a logging device and later send it to Bucher Hydraulics for analysis.

4. Examples

Observe below the vast variety of effects and errors you can isolate and identify even though they might origin in the most different domains of the whole hydraulic and mechanic system using just four signals.

The capacity to log driving curves over a long time is particularly helpful because the slightest circuit-, timing-, or assembly-fault, in case it leads to a sporadic error, can cause time consuming search activities and often leads to the need to exchange entire parts of the system.

4.1. Motor Starts too Late at Up Travel

The customer claims that there is a significant jerk sometimes when the lift is starting to ride upwards.

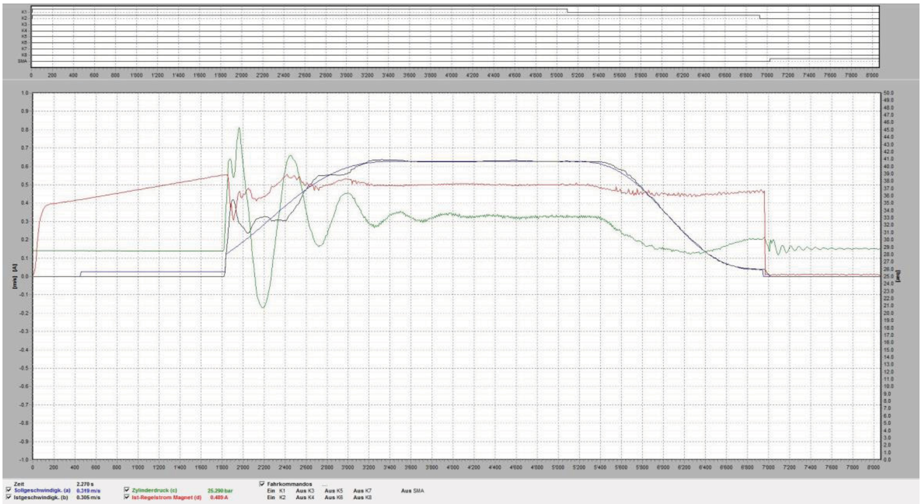

Figure 6: Motor Started Approximately 2 Seconds too Late

The explanation: The logging device was installed to monitor the installation for several weeks. The analysis of the measurements showed that once in a while this cabinet produces a delay between the commands to the valve and the motor contactor. When the command to the valve comes prior to the motor the lift jerks.

4.2. Localizing the Source of a Disturbance – Shaft

In the early introduction of the valve, a customer claimed that he could falsely activate the safety signal (SMA) by jumping in the lift while riding downwards. Bucher Hydraulics thereupon integrated the PSQ-analysis into the evaluation algorithm as in Figure 7. This algorithm localizes the source of a disturbance in the hydraulic lift system.

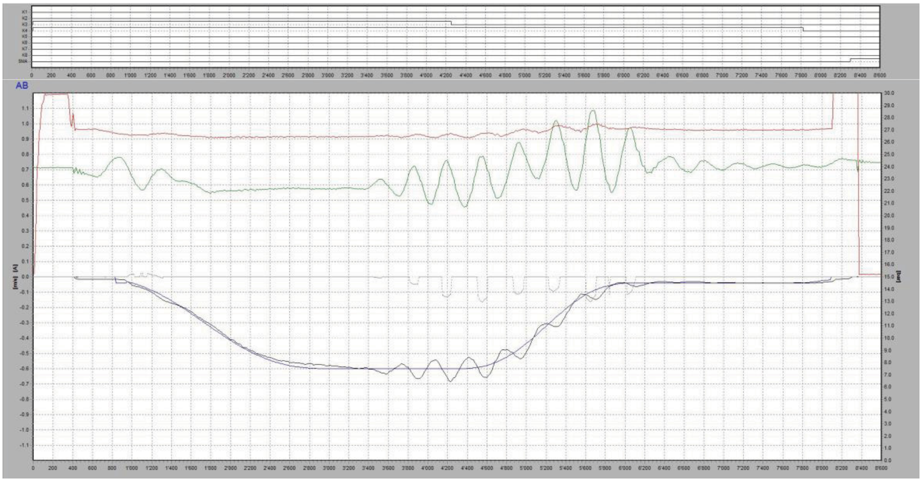

Figure 7: PSQ for Jumping People in the Cabin

The algorithm calculates the phase between the pressure disturbance and the volumetric flow disturbance. Thus it can reliably distinguish between a disturbance originating in the shaft – a changing or moving load, rail errors, or cylinder errors – or in the valve.

4.3. Localizing the Source of a Disturbance – Valve

To show the success of the PSQ-analysis Figure 8 is a curve with a damaged solenoid ram in the proportional pilot. During the long ride the solenoid sticks and the current falls until the solenoid breaks free. In the following wave the PSQ clearly signalizes a positive result localizing the origin in the valve.

In a real lift this valve will deny to send the SMA signal. Thus the lift control will block the lift operation.

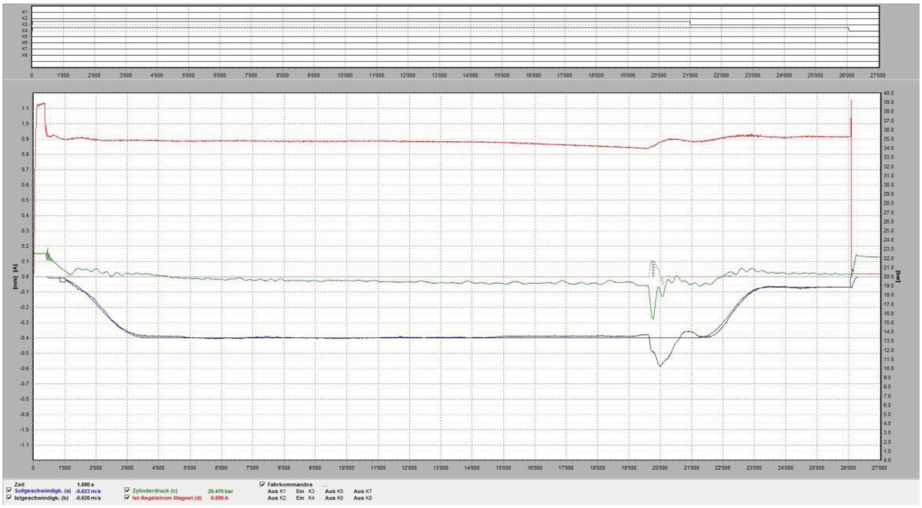

Figure 8: PSQ for a Damaged Solenoid Ram

4.4. Pressure Relief Valve Badly Adjusted

The customer claims that at full load the lift does not achieve full speed upwards.

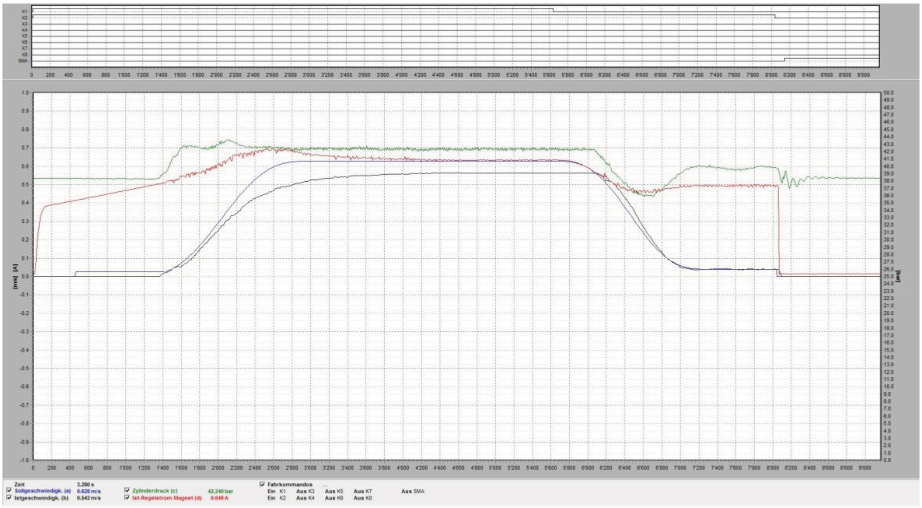

Figure 9: Dynamic Pressure is Limited

Explanation: The pressure relief valve is set to a value, that the customer quoted in his order. While often the cabin ends up being lighter, it sometimes end up being heavier. In this case the pressure will be cut off when it reaches the set value. In a typical lift installation this happens in the second half of the acceleration. So the lift accelerates smoothly to a value below the desired speed as seen in Figure 9.

4.5. Desired Speed Higher than Pump Can Provide

The case shown above must not be confused with the case where a desired speed is parameterized which is higher than the pump can provide.

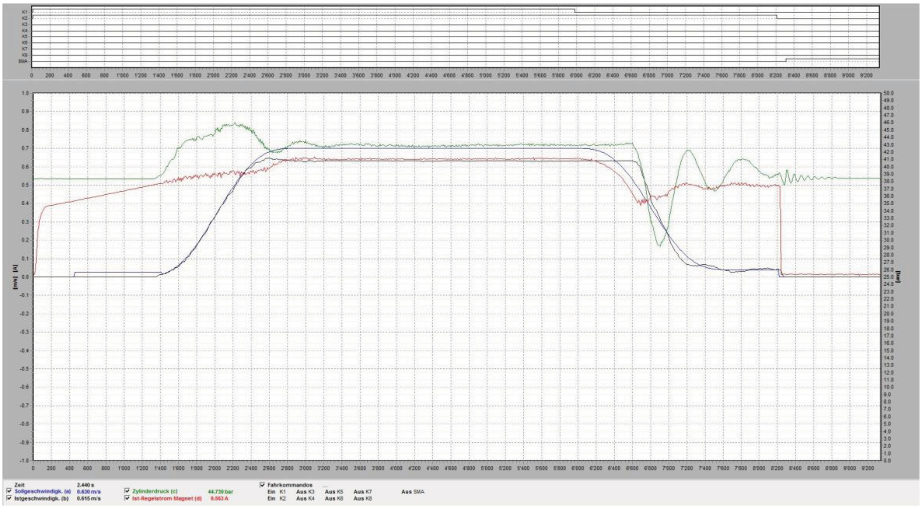

Figure 10: Volumetric Flow is Limited

In this case, not the dynamic pressure but the volumetric flow is limited. The cabin accelerates to the speed that the pump can provide. Reaching this value, the speed suddenly stays constant. The pressure at acceleration is significantly higher at full speed. Hydraulic/mechanical interactions also lead to increased pressure changes at deceleration. Overall, an expert can easily distinguish between these two cases using such curves.

4.6. Mechanical Stop in the Shaft

The customer claims that sometimes the lift does not achieve the lower stop and/or sometimes it starts with a significant jerk from the lower stop upwards. Driving curves of the lift are do not show any special behaviour. The logging device is installed.

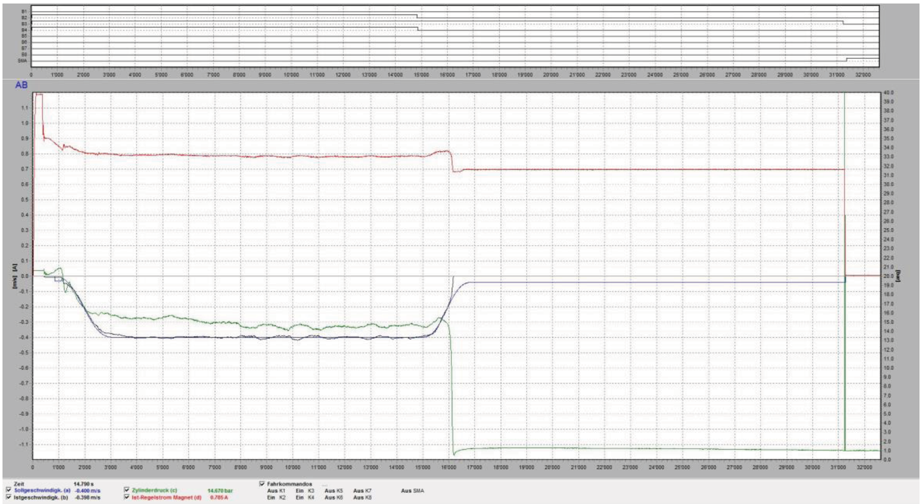

Figure 11: Mechanical Failure in the Shaft

Explanation: As Figure 11 shows, in the last centimeter of the downward ride the pressure can break down. Clearly, some mechanical obstacle carries the entire load. Later, the customer confirmed that the cylinder fastening loosened from time to time.

5. Summary

The iValve is a family of electronically controlled lift valves. Every iValve is equipped with an array of sensors and algorithms to receive and achieve various information. This information enables the software of the valve to do extensive analysis concerning the valve as well as the attached system. Some of these algorithms are called iTeach. They help the valve to adopt to its environment. Besides, every accessible information is helpful to provide and enhance remote customer support.

6. References

/1/ Goenechea et al., WO 2011/003210 A1, 2011, Neuheim, Switzerland

/2/ Normenausschuss Maschinenbau (NAM) im DIN, DIN EN 81-2:2010-08, 2010 Berlin, Germany